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Scanning X-ray Microtopographs of Misfit Dislocations at SiGe/Si Interfaces

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Introduction: SiGe/Si heterostructures are used to fabricate high-speed transistors that extend the range of applications of Si technology. Appropriate relaxed SiGe substrate films for epitaxial growth of strained carrier channels relax by the formation of long misfit dislocations at the SiGe/Si interface and have low threading dislocation densities.[1] Misfit dislocations at $Si_{1-x}Ge_x$/Si interfaces that have negligible strain relaxation have been imaged by x-ray microdiffraction using the 004 diffraction peak of both the $Si_{1-x}Ge_x$ layer and Si(001) substrate.[2] Studying these low-defect-density films aids in our understanding of how the microstructure of fully relaxed SiGe films evolves.

Methods and Materials: Pseudomorphic films of $Si_{1-x}Ge_x$ were grown by ultra-high-vacuum chemical vapor deposition on Si(001) substrates. Three samples were studied: 1) 450nm of $Si_{0.85}Ge_{0.15}$, 2) 317nm of $Si_{0.87}Ge_{0.13}$ on 43nm of $Si_{0.91}Ge_{0.09}$ on 43nm of $Si_{0.96}Ge_{0.04}$, and 3) 257nm of $Si_{0.83}Ge_{0.17}$ on 349nm of $Si_{0.87}Ge_{0.13}$ on 43nm of $Si_{0.91}Ge_{0.09}$ on 43nm of $Si_{0.96}Ge_{0.04}$. Monochromatic x-rays were microfocussed using a tapered glass capillary. Beam size on the films was ~5 - 10 μm. For the scanning microtopographs, diffraction from the 004 $Si_{1-x}Ge_x$ and Si substrate peaks was measured while rastering the sample by 2-μm steps on an x-y stage. Rocking curve scans were also measured as a function of sample position (θ-x meshes). Figures can be found in Ref. 2.

Results: At the $Si_{1-x}Ge_x$ layer peak, a decrease in diffracted intensity is found at dislocations, with features as narrow as 4mm. The dislocation distribution is inhomogeneous, and the varying darkness of the lines indicates, as expected, that the dislocations occur in pileups along <111> planes. Similar features are seen using the Si peak; however, the diffracted intensity increases at the dislocations. The θ-x meshes show that where the SiGe diffracted intensity decreases at dislocations, the rocking curve peak width has increased, yet the integrated intensity remains fairly constant. In addition, the rocking curve peak centers shift, indicating a local tilting of the crystal lattice by the dislocations. Topographs of the top two layers of sample 3 are very similar, indicating that the crystal distortions due to dislocations located near the $Si_{1-x}Ge_x$/Si interface extend throughout both epitaxial layers.

Conclusions: The intensity contrast observed for topographs of the $Si_{1-x}Ge_x$ layer are due primarily to the broadening of the rocking curve by the strain field of the dislocations. In previous studies of highly relaxed films, the contrast was due to the tilting of local regions.[3] The contrast mechanism for the substrate, which yields a “negative image” of the layer topograph, is due to loss of extinction caused by crystal lattice distortion around the dislocations. That is, kinematic rather than dynamic scattering occurs, thus giving increased intensity at those locations. The data also reveal the inhomogeneous distribution of misfit dislocations at $Si_{1-x}Ge_x$/Si interfaces. Finally, we have also shown that the distortion of the crystal lattice extends throughout the entire epitaxial $Si_{1-x}Ge_x$/Si layer structure.

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References:

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